X-752-71-212
PREPRINT

NASA TM X-65649

# NASA BALLOON-AIRCRAFT RANGING, DATA AND VOICE EXPERIMENT

SHELDON WISHNA



JULY 1971



GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

CONTENTS

## LIST OF ILLUSTRATIONS

LIST OF TABLES

NASA BALLOON-AIRCRAFT RANGING,
DATA AND VOICE EXPERIMENT

## 1. INTRODUCTION

An air traffic control system must provide voice and data communications along with a surveillance capability. In this regard, many studies (as well as the performance of several implemented systems) clearly indicate the significant advantages of using one or more satellites for air traffic control purposes. The National Aeronautics and Space Administration (NASA) has made extensive investigations in cooperation with many foreign and domestic agencies and private corporations, e.g., the Department of Transportation (DOT) and the European Space Research Organization (ESRO), to determine the best satellite air traffic control system approach. These studies have led to a comprehensive air traffic control experiment called PLACE (Position Location and Aircraft Communication Equipment), which will begin in 1973 with the Applications Technology Satellite-F (ATS-F).

ESRO has scheduled a series of balloon-aircraft tests for the third quarter of 1971 to define more clearly the technical parameters of an L-band air traffic control system. (A frequency in the L-band was selected for the balloon-to-aircraft links because this frequency band is considered a prime candidate for an eventual operational air traffic control system. The satellite relay will be simulated by means of a balloon platform.) ESRO has invited NASA to participate in the test program, and NASA proposes, as one of its contributing programs, to conduct a series of tests to evaluate some of the air traffic control concepts proposed for the ATS-F. As a result of the NASA test program, the experimental objectives listed in Table 1-1 are expected to be achieved.

## 2. SYSTEM CONCEPT

The ranging, data, and voice communication system to be demonstrated during the balloon-aircraft test program has evolved principally from studies conducted by NASA, ESRO, and DOT. To provide for this experiment within the limited time and facilities available, the test program is limited in scope and is designed principally to demonstrate concepts, to obtain limited scientific data, and to evaluate technological approaches; it should not be considered as a NASA recommendation of any specific air traffic control system.

Table 1-1

Major Experiment Objectives

- Evaluate PLACE ATC concept prior to ATS-F application
- Demonstrate continuous and time division multiplex two-way tracking of aircraft and compare with radar track
- Evaluate duplex NBFM voice channels
- Evaluate duplex data channels
- Demonstrate aircraft command and control, using data channel
- Relate received carrier magnitude and frequency to propagation effects
- Obtain operational experience with the transceiver in an aircraft environment
- Define techniques for coordination of airborne and ground experimental and recording procedures
- Evaluate test procedures to determine system performance
- Define data to be collected and procedures required for presentation of the data

The balloon-aircraft tests will be conducted in the Southwest of France (see Figure 2-1). There are five major subsystems in this experiment:

- Ground station
- Balloon platform
- Radar tracking station
- Aircraft
- Data processing center.

The ground station, which is colocated with the balloon launch facility at Aire-sur-l'Adour, France, generates and transmits in the proper modulated format the data, voice, ranging, control, and command signals required for the experiment. It also receives the return ranging, data, and voice signals, which are demodulated, reduced, and recorded for eventual data processing. The ground station also has facilities for monitoring the balloon transmission and for receiving telemetry data from the balloon.

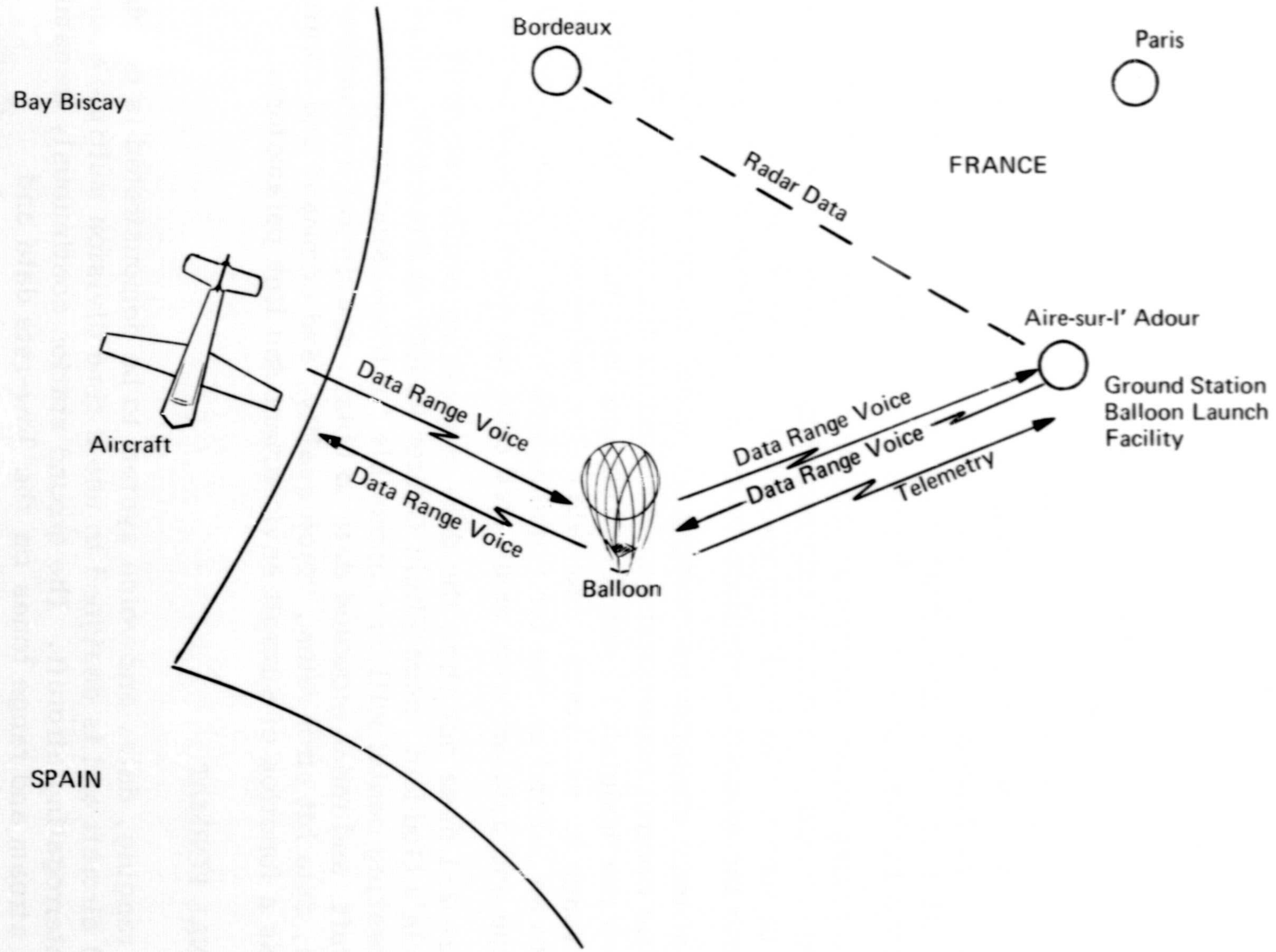



Figure 2-1. Pictorial Test Facilities—Balloon-Aircraft Ranging, Data, And Voice Experiment System

The balloon platform contains a telemetry link, a radar beacon, and a duplex transponder system. The telemetry link provides power output, temperature, and altitude information, among other items. The radar beacon provides an enhanced signal return to the radar. The duplex transponder receives the modulated UHF carrier from the ground station and retransmits unaltered, except for a phase reversal, the modulated carrier at an L-band frequency for reception by the aircraft and the ground station monitoring receivers. In a similar manner the duplex transponder receives a modulated L-band carrier from the aircraft and retransmits unaltered, except for a phase reversal, the modulated carrier at a UHF frequency for reception by the ground station.

The balloon altitude, approximately 40 km, will satisfactorily represent the geometry that would be obtained with a synchronous satellite and an aircraft. The balloon position will remain relatively stationary, since the wind velocities are very low during the time of the year when the tests are scheduled. Each balloon launched will remain aloft approximately 10hr.

The tracking radar, located at Bordeaux, France, is a European version of the FPS-16 radar. A digital printout of the balloon and aircraft positions as a function of time is obtained from the radar. These radar position data are used to compute the aircraft-to-balloon range obtained from the ranging tones.

The aircraft contains the breadboard model transceiver built for the ATS-F air traffic control experiment and modified for this program. The transceiver receives the modulated L-band carrier and demodulates the carrier, giving output range tones, voice, and data. The output range tones are remodulated onto an L-band carrier for transmission to the balloon. Aircraft-generated voice and data are also modulated onto the same L-band carrier.

Figure 2-1 does not show the data processing center, since it will be located at NASA's Goddard Space Flight Center (GSFC) at Greenbelt, Maryland. The data processing center will be responsible for processing the ground station, aircraft, and radar recorded data to obtain meaningful evaluations of aircraft range, data bit error rates, voice quality, and command and control reliabilities as a function of aircraft environment and link parameters.

## 3. SIGNAL FORMAT

The ranging, data, and voice system to be demonstrated is capable of servicing 250 aircraft and is designed to use a time division multiple access scheme for interrogating aircraft. The ground station continuously transmits a 600-bps data stream and range tones on the low-rate data and surveillance carrier. The 600-bps data contain a sequence of words that activates the transceiver logic and internal circuits, selects the time slot for transmission, selects the number of transmissions per frame, and provides voice, data, and emergency channel status indication. To minimize false

command and control signals because of noise, the aircraft transceiver will only decode the low-rate data during the epoch slot, the 10 status slots, and the assigned transceiver slot. It has been estimated that, for high-performance aircraft, range and low-rate data interrogation will employ an ordered system in which interrogation of an aircraft will be limited to approximately 200 msec of time. Thus each aircraft slot (epoch, status, assigned, etc.) is 200 msec long. High-rate data channel and voice channel access will be upon request, with immediate access procedures provided for emergencies. A voice and high-rate data transmission can be sent from the interrogated aircraft, or from other aircraft within the air traffic control net, simultaneously with the ranging and low-rate data transmission from the interrogated aircraft. For the balloon-aircraft experiment, only one ranging and low-rate data channel, one voice channel, and one high-rate data channel will be used simultaneously with one aircraft.

The transmission spectrum is shown in Figure 3-1. Except for the difference in carrier and subcarrier frequencies, this spectrum is identical for all links. The transmitted signal consists of three carriers: $F_{C1}$, $F_{C2}$, and $F_{C3}$; $F_{C1}$ contains the ranging and low-rate data information, $F_{C2}$ contains the high-rate data information, and $F_{C3}$ contains the voice transmission. The ranging function is provided by two individual ranging tones (8575 Hz and 7350 Hz), double sideband amplitude modulated onto $F_{C1}$. The low-rate data are generated at a 600-bps rate and phase-shift-keyed (PSK) modulated onto a quadrature component of the same carrier $F_{C1}$. Sufficient carrier power is reinserted to enable carrier lockon at the transceiver. For a $1.5^{\circ}$ rms phase error, the two tones will provide a 150-m rms two-way ranging error as well as a two-way ambiguity range resolution of approximately 130 nmi. This ambiguity resolution will be adequate for the anticipated balloon-aircraft ranges. The high-rate data are generated at a 1,200 bps rate and differentially coherent phase shift keyed (DCPSK) modulated onto carrier $F_{C2}$. The high-rate data channel normally provides for a general data service, but during the balloon aircraft test a pseudo-random code data transmission will be used on this channel to determine bit error statistics. The voice signal is narrowband frequency modulated onto carrier $F_{C3}$. The use of narrowband FM restricts the RF bandwidth to approximately 10 kHz and permits the reception of good quality voice at low carrier-to-noise levels. Table 3-1 presents the frequency values of the transmitted carriers for each link of the balloon-aircraft experiment.

## 4. POWER REQUIREMENTS

### 4.1 Link Calculations

The critical link with respect to power limitations is the balloon-aircraft link. The ground-to-balloon links will not be power limited, primarily because of the lower path loss of the UHF transmission and the use of a

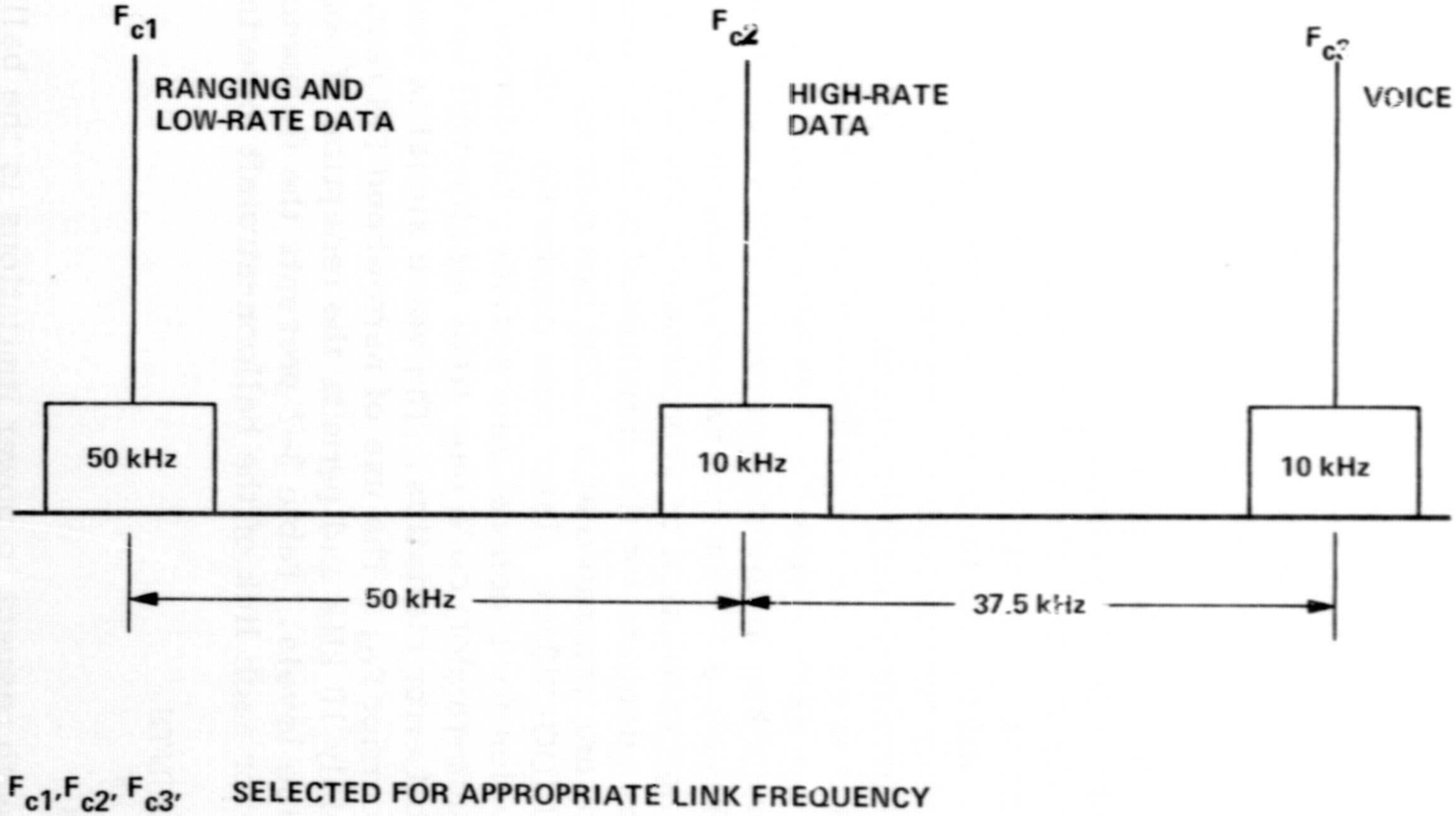



Figure 3-1. Signal Format Spectrum

Table 3-1

Frequency Allocation

| Link | $F_{C1}$ MHz | $F_{C2}$ MHz | $F_{C3}$ MHz |
|---|---|---|---|
| Ground-to-balloon | 444.1250 | 444.0750<br>444.0000<br>443.9250 | 444.0375<br>443.9625<br>443.8875 |
| Balloon-to-aircraft | 1550.3550 | 1550.4050<br>1550.4800<br>1550.5550 | 1550.4425<br>1550.5175<br>1550.5925 |
| Aircraft-to-balloon | 1651.3750 | 1651.4250<br>1651.5000<br>1651.5750 | 1651.4625<br>1651.5375<br>1651.6125 |
| Balloon-to-ground | 400.7750 | 400.7250<br>400.6500<br>400.5750 | 400.6875<br>400.6125<br>400.5375 |

high-gain antenna at the ground station. The aircraft-to-balloon link has approximately 17 dB more transmitter power than the balloon-to-aircraft link. Table 4-1-1 summarizes the link calculations for the balloon-to-aircraft and aircraft-to-balloon links. The values used for the link parameters are nominal worst case; e.g., the minimum anticipated antenna gains are used and the path loss is computed for the maximum slant range of 240 statute miles. Table 4-1-1 shows that an experimental system requirement of 49 dB-Hz power density (voice: 46 dB-Hz; high-rate data: 42.8 dB-Hz; and low-rate data and range tones: 42.0 dB-Hz) can be achieved.

## 4.2 Channel Requirements

The power budget allocations for the high-rate data channel, the low-rate data-range tones channel, and the voice channel were selected to meet anticipated satellite air traffic control performance requirements. These power levels were selected to minimize eventual satellite power requirements and to eliminate the necessity for complex high-gain antenna systems. Although no firm air traffic control standards have been established for the performance requirements of the data, ranging, and voice channels, reasonable values for these parameters are as follows:

| | |
|---|---|
| Data channels: | $10^{-5}$ error probability |
| Location accuracy: | 1 nmi |
| Voice: | 95% MRT word intelligibility |

### 4.2.1 Voice Channel

An adaptive narrowband frequency modulation (ANBFM) technique is used for the duplex voice communications. The ANBFM voice communication system achieves good quality voice reception under low carrier-to-noise conditions by employing optimized voice processing of both input and output speech and by using a unique adaptive demodulation concept. The system can achieve a 95% modified rhyme test (MRT) voice intelligibility at a carrier-to-noise power density level of 46 dB-Hz but will exhibit thresholding at extremely low carrier-to-noise levels. To eliminate this thresholding effect, the ANBFM was designed to give an 85% MRT word intelligibility at a carrier-to-noise level of 46 dB-Hz. The elimination of thresholding is considered extremely important if the voice system is subjected to severe fading, since this will minimize the number of complete dropouts. Operation of the voice channel at this power density level will still permit the goals of this experiment to be realized. Figure 4-2-1 is a plot of the percent MRT word intelligibility as a function of received $C/N_o$ power density.

Table 4-1-1

Balloon-to-Aircraft and Aircraft-to-Balloon Link Calculations

| Item | Balloon to Aircraft | Aircraft to Balloon | Units |
|---|---|---|---|
| Transmitter | | | |
| Power amplifier output | 0 | 17.0 | dBw |
| Cable-diplexer losses | -3.5 | -2.0 | dB |
| Antenna gain | +2.0 | +4.0 | dB |
| Effective radiated power | -1.5 | +19.0 | dBw |
| Path loss | -149.8 | -150.2 | dB |
| Fading | -1.0 | -1.0 | dB |
| Receiver | | | |
| Antenna gain | +4.0 | +2.0 | dB |
| Cable-diplexer losses | -2.0 | -3.5 | dB |
| Carrier power | -150.3 | -133.7 | dBw |
| Thermal noise | -204.0 | -204.0 | dBw-Hz |
| Noise figure | +5.0 | +5.0 | dB |
| Noise power density | -199.0 | -199.0 | dBw-Hz |
| Carrier-to-noise power density | +48.7 | +65.3 | dB-Hz |
| System requirement | | | |
| Voice channel carrier-to-noise power density | 46 | 46.0 | dB-hz |
| High-rate data channel carrier-to-noise power density | 42 | 42.0 | dB-Hz |
| Low-rate data and range tones channel carrier-to-noise power density | 42 | 42.0 | dB-Hz |
| Total carrier-to-noise power density | 48.9 | 48.9 | dB-Hz |
| Margin | -0.2 | +16.4 | dB |

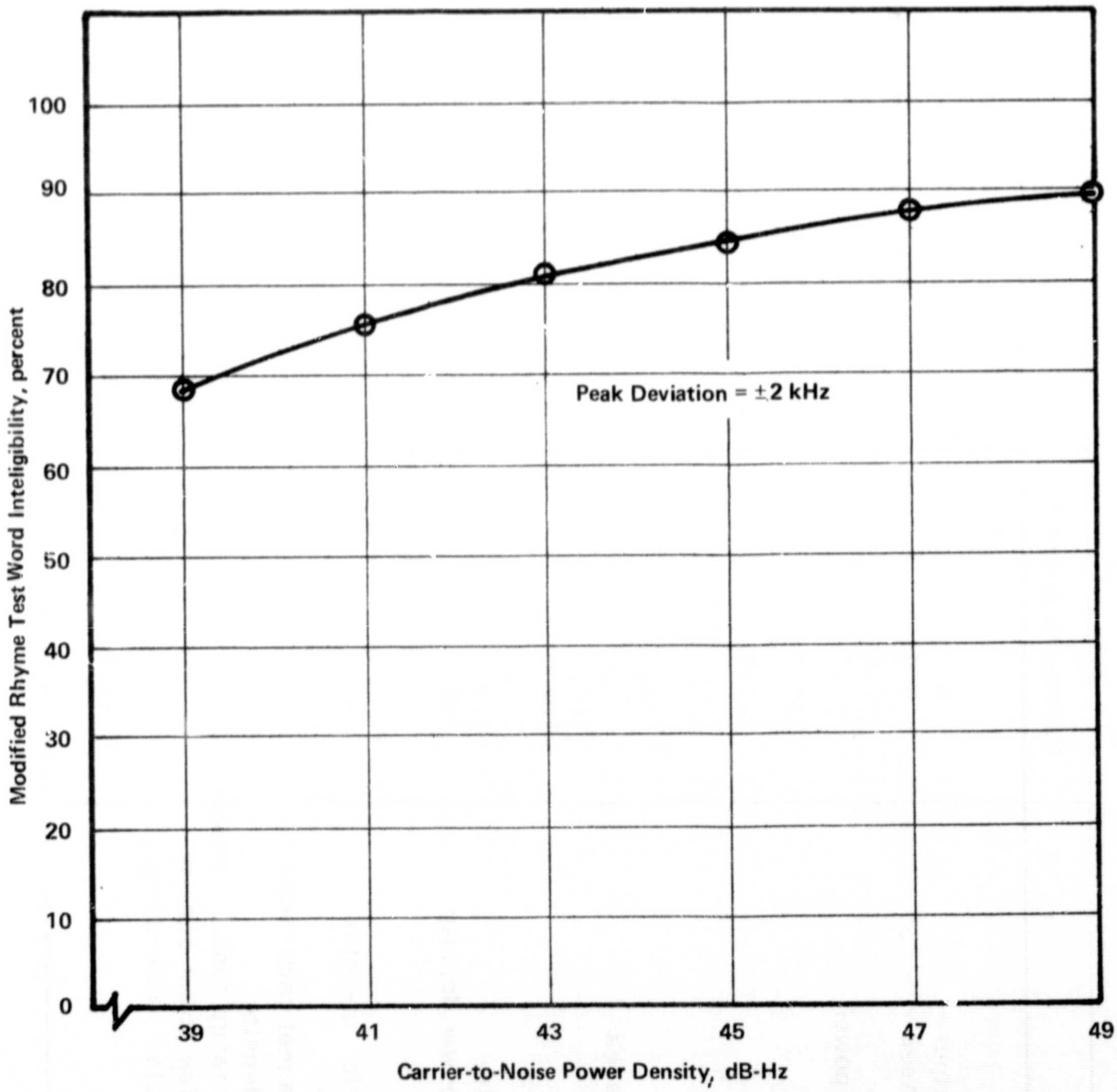



Figure 4-2-1. Modified Rhyme Test Word Intelligibility Of Adaptive Narrowband Frequency Modulation Voice Communication System

### 4.2.2 High-Rate Data Channel

The high-rate data channel operates at 1,200 bps and is required to have a bit error probability of $10^{-5}$. The $C/N_o$ needed at the demodulator is obtained from the following relationship:

$$C/N_o(\text{dB-Hz}) = E/N_o(\text{dB}) + \text{channel bandwidth (dB-Hz)} + \text{demodulator losses (dB)}.$$

For the high-rate data channel,

$E/N_o$ = energy per bit-to-noise power density ratio = 11 dB
(differential coherent PCM/PSK at $10^{-5}$ bit error probability)

Channel bandwidth = 1200 Hz = 30.8 dB-Hz

Demodulator losses = 1 dB (assumed)

$C/N_o$ = carrier-to-noise power density = 11 + 30.8 + 1 = 42.8 dB-Hz.

A carrier-to-noise power density allocation of 42.8 dB-Hz will meet the requirements of the high-rate data channel.

### 4.2.3 Low-Rate Data-Range Tones Channel

The low-rate data channel operates at 600 bps and is required to have a bit error probability of $10^{-5}$. Using the relationship defined in paragraph 4.2.2, the needed $C/N_o$ can be calculated as

$$C/N_o = 11 + 27.8 + 1 = 39.8 \text{ dB-Hz}.$$

The balloon- aircraft experiment will use two tones to determine the aircraft-to-ground station range. These tones will not be measured simultaneously, since there is equipment at the ground station for measuring only one tone phase at a time. Analysis has shown that to meet an overall aircraft location accuracy of 1 nmi the two-way range should be measured to rms accuracy of 150 m. Assuming that the tone phase angle in a noisy environment can be measured to within 1.5°, the minimum high-frequency tone needed is obtained as follows:

$$f = 1/240\ (C/\lambda) = 1/240\ (2.988 \times 10^{8}/150) = 8.34 \text{ kHz}.$$

The high-frequency tone used in the balloon - aircraft test is 8.575 kHz, which will give an unambiguous two-way range resolution of 19.4 nmi. The lowest ambiguity tone to be employed for these tests is 1225 Hz, which will be derived from the difference frequency of the two transmitted tones

8.575 kHz and 7.350 kHz. The use of a frequency difference technique permits maximum power utilization for the high resolution measurements, since both tones can be used to directly measure the high resolution range. The frequency difference technique will permit a two-way range ambiguity determination of 130 nmi.

The rms phase error of the tones measured at the ground station will be a function of the signal-to-noise of the tone and the integration time of the correlated phase measurement. The transceiver has the capability of operating in a time division multiplex mode, which will require a minimum integration time of 120 msec. The tone $C/N_o$ required is computed from the following relationship:

$$C/N_o(\text{dB-Hz}) \approx 1/2T\Theta^2 + \text{demodulator loss (dB)}.$$

For the range tone requirement specified,

$$\Theta = \text{rms phase error in radians} = 0.0262 \text{ radians}$$

$$T = \text{integration time} = 120 \text{ msec}$$

$$C/N_o = 38.8 \text{ dB-Hz}.$$

The sum of the low-rate data and the range tone $C/N_o$ is as follows:

$$\text{Low-rate data } C/N_o = 39.8 \text{ dB-Hz}$$

$$\text{Range tone } C/N_o = 38.8 \text{ dB-Hz}$$

$$\text{Total low-rate data and range tone } C/N_o = 42 \text{ dB-Hz}.$$

## 5. EQUIPMENT

The Balloon-Aircraft Ranging, Data, and Voice Experiment will make maximum use of existing PLACE equipments and designs as well as applicable ESRO ground station, balloon, and aircraft equipments. Figure 5-1, the system block diagram for the experiment, shows within dashed lines the NASA-supplied equipments that are located in the ground station and the aircraft. Table 5-1 contains a list of the system equipments required for the experiment, including a summary of the prime functions performed by these equipments.

### 5.1 Ground Station

The NASA ground equipment will be located in the ESRO/ESTEC (European Space Research and Technology Center) ground station, which employs two switchable UHF antennas for communicating with the balloon. One antenna covers the zenith to 45° elevation angle and the other the 45° elevation angle to the lowest usable elevation angle. The antenna for the upper elevation angles is a fixed mounted

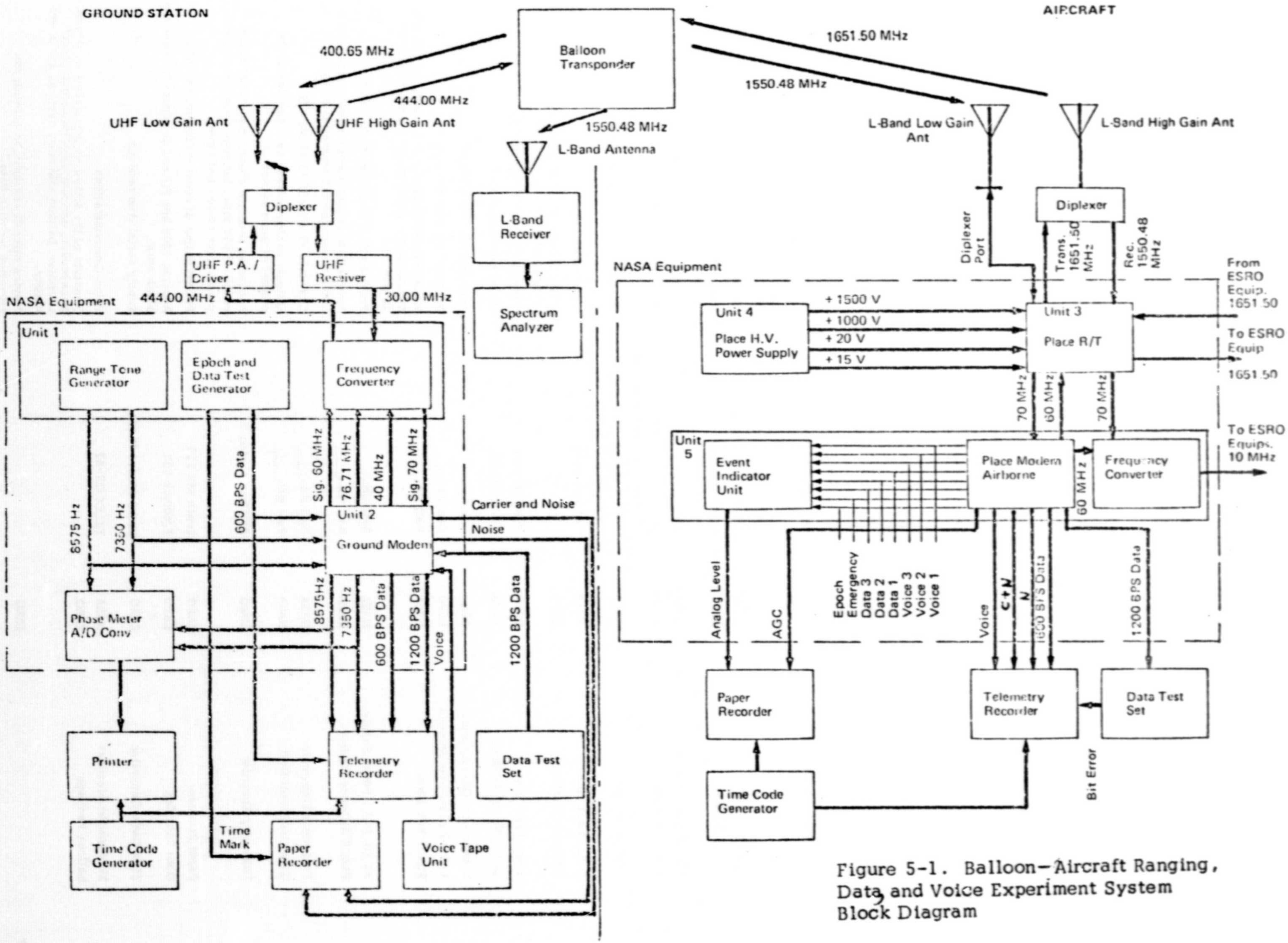



Figure 5-1. Balloon–Aircraft Ranging, Data and Voice Experiment System Block Diagram

# Table 5-1

## Equipment List, Balloon-Aircraft Ranging, Data, and Voice Experiment

| Location | Item | Source | Type/Model | Function |
|---|---|---|---|---|
| Ground Station | UHF Low Gain Antenna | ESRO | | Transmit/Receive Antenna - 4 unit corner |
| | UHF High Gain Antenna | ESRO | | Transmit/Receive Antenna - Archimedes Spiral |
| | Diplexer | ESRO | | Transmit/Receive Channel Separation |
| | UHF Power Amplifier | ESRO | | Class C Power Amplification |
| | UHF Driver Amplifier | ESRO | HP 230 A | Linear Amplifier |
| | Frequency Converter | NASA | Bell Model No.____ | Converts transmit 60 MHz to 444 MHz and receive 30 MHz to 70 MHz |
| | Range Tone Generator | NASA | Bell Model No.____ | Generates 8575 Hz and 7350 Hz tones |
| | Epoch and Data Test Generator | NASA | Bell Model No.____ | 600 bps command and control, 1200 bps, test signal, 1 minute time marker |
| | Ground Modem | NASA | Bell Model No.____ | Demodulates voice, data, and range tones, modulates voice, data, and range tones and converts to 60 MHz |
| | Phase Meter | NASA | Dranetz Model No. 202A | Measures the phase angle of the received range tones relative to the transmitted tones |
| | A/D Converter | NASA | HP 5245L, HP 5265A | Converts analog phase angle reading to BCD readout |
| | Printer | ESRO | HP 5050B | Angle readout of range tone phase shift |
| | Telemetry Recorder | ESRO | Phillips Analog 7 | Record on separate channels received 8575 Hz tone, received 7350 Hz tone, received 600 bps, received 1200 bps, transmitted 600 bps, time code data |
| | Data Test Set | ESRO | Fredrick Model 600 | Generate PN sequences |
| | Paper Recorder | ESRO | Brush MK 260 | Provide analog carrier plus noise and analog noise record |
| | Time Code Generator | ESRO | Datum Model 9310 | Supply serial and BCD readout of clock |
| | L-Band Receiver | ESRO | Nems Clark 1037G RF Head RFT1040 Modified | Reception of balloon L-band transmission |
| | UHF Receiver | ESRO | Nems Clark 1037G RF Head RFT102A | Reception of balloon UHF transmission |
| | L-Band Antenna | NASA | Polarad CA-L | Receive Antenna |
| | Spectrum Analyzer | ESRO | | Adjust power levels and monitor balloon L-band transmission |
| | Voice Tape Unit | ESRO | Sony TC 366 | Play voice tapes into system |
| | Microphone/Headset | NASA | TELEXCS-61 | Voice communications |
| Aircraft | L-Band Low Gain Antenna | ESRO | Boeing | Transmit Receive Antenna |
| | L-Band High Gain Antenna | ESRO | Dioscures | Transmit Receive Antenna |
| | PLACE R/T Unit | NASA | Bell No.____ | Receives and transmits in L-band, outputs and inputs at IF. A low power L-band interface is provided. |
| | PLACE H.V. Power Supply | NASA | Bell No.____ | Provides D.C. voltages to R/T unit |
| | PLACE Airborne Modem | NASA | Bell No.____ | Identical to ground station modem except for a 600 bps decoder and activating circuitry |
| | Frequency Converter | NASA | Bell No.____ | Converts 70 MHz IF to 10 MHz IF |
| | Event Indicator Unit | NASA | Bell No.____ | Outputs analog voltage as a function of the number of input events |
| | Telemetry Recorder | ESRO | Phillips Analog 7 | Record on separate channels received voice, received 600 bips, bit error count, time code, carrier plus noise, and noise |
| | Paper Recorder | ESRO | Brush MK 260 | Record output of event indicator, and AGC |
| | Data Test Set | ESRO | Fredrick 600 | Receive 1200 bps PN and determine bit error and block error |
| | Time Code Generator | ESRO | EECO Model 1125A | Supply serial time readout |
| | Microphone/Headset | NASA | TELEX CS-61 | Voice Communications |
| Balloon | Balloon Package | ESRO | | Consists of the following principle subsystems - transponder, antenna systems, radar beacon, altimeter, balloon telemetry system, and power supply. |
| Radar Facility | | ESRO | | Provide aircraft and balloon azimuth and elevation position data. |

Archimedes spiral having a nominal gain of 7 dB. The antenna for the lower elevation angles is a four-unit, corner reflector type having a nominal gain of 18 dB. This antenna is fixed in elevation but movable in azimuth under the control of a monopulse receiving system. These antennas are used for both transmit and receive by employing a diplexer between the antenna and the ground station power amplifier and receiver.

The UHF receiver used is a standard NEMS Clark 1037C with a crystal-controlled RFT 102A tuner head. The 30 MHz intermediate frequency output of the receiver is converted to a 70 MHz intermediate frequency by a frequency converter and is then delivered to the ground modem. The frequency converter also derives the 444.00 MHz input to the power amplifier from the 60 MHz intermediate frequency input from the ground modem. The ground station power amplifier, a class C, takes a 10 mW 444.00 MHz signal from the frequency converter and amplifies the signal power level to 15 W.

Except for the elimination of the decoder and activation circuitry, the ground modem is identical to the modem unit located in the aircraft transceiver; it consists of a modulator section and a demodulator section. The modulator section contains a narrowband FM voice modulator, a DCPSK high-rate data modulator, and a reinserted carrier, PSK/suppressed carrier AM quadratically phased ranging and low-rate data modulator. The outputs of each of the modulators are summed and the composite signal is frequency translated to 60 MHz. The modem unit contains controls for selecting any one of three data channel frequencies and any one of three voice channels. An amplitude control is provided to adjust the power output level of each modulator.

The ground modem signal inputs are two range tones, low-rate data, high-rate data, and voice. The two range tones are generated continuously by the range tone generator, which consists of two highly stable oscillators at 8575 MHz and 7350 MHz, each having a long-term stability of one part in $10^{-5}$. The low-rate data input, which provides for the command and control function, is generated at 600 bps. These low-rate data are obtained from the epoch and data test generator, which provides the following outputs:

a. Generates each minute an epoch sync signal (frame sequence)

b. Generates aircraft address, slot position, and rate of interrogation

c. Provides status signals on the use of the three voice channels, the three high-rate data channels, and emergency

d. Controls transmissions of the aircraft transponder.

The epoch and data test generator performs these functions by transmitting a coded 24-bit phrase containing three 8-bit words at selected times relative to a fixed wired epoch code. The 24-bit code is normally manually set into the epoch and data test generator by a bank of 24 switches. For the balloon - aircraft experiment, the epoch and data test generator will have 10 command and control sequences hard-wired to a 10-position stepping switch. The stepping switch will change position once a minute so that a new command or control function will be automatically transmitted to the aircraft, each minute. Some of the commands or control functions generated will have errors inserted into the code to demonstrate the system's sensitivity to coding errors. The high-rate data input (1,200 bps) is obtained from the Frederick 600 Data Test Set, which outputs a 2,047-bits-per-frame pseudo-random code. The voice is obtained from a recording played on a commercial quality audiotape recorder. The tape will contain modified Rhyme test words, phonetically balanced words, speech communication index meter (SCIM) signals, and typical air traffic control messages.

The phase angle shift of the received demodulated range tones with reference to that generated by the range tone generator is measured by a fast-acting phase meter, the Dranetz Sampling Vector Computer System Series 202. This unit is capable of measuring at low signal-to-noise levels both continuous wave and gated tones, utilizing a sampling and integration technique. The output from the phase meter is an analog voltage of the phase angle; this voltage is converted to a BCD format by an analog-to-digital converter. The BCD output from the analog-to-digital converter is delivered to an HP 5050B Digital Recorder. The digital recorder will either use an optical HP Clock or accept as an input a BCD time signal from the time code generator. The digital recorder will not print until a ready-to-readout pulse is received from the phase meter. The printout will contain both the analog voltage of the phase angle measured and the time to the nearest tenth of a second. The time code generator located at the ground station provides both a BCD parallel readout and a NASA 36-bit serial code readout of time in hours, minutes, seconds, and tenths of seconds. The time code generator provides a time reference for coordinating and evaluating the recorded data. A telemetry recorder is provided for recording the epoch and data test generator 600-bps output; the time code generator NASA code; and the ground modem demodulated 8575 Hz tone, 7350 Hz tone, 600-bps data and 1,200-bps data. A Phillips Analog 7 telemetry recorder is used with FM subcarriers to provide a wideband recorder capability down to dc. A paper recorder is provided to record the analog voltage of the carrier plus noise measurement and the analog voltage of the noise measurement obtained from the ground modem.

The ground station will have an L-band horn antenna and an L-band receiver for reception of the balloon L-band transmission. The 30 MHz intermediate frequency output of the L-band receiver will be monitored by the spectrum analyzer. The display on the spectrum analyzer will permit field

station personnel to set at the ground station the relative power levels for the ranging, data, and voice channels by manually adjusting the modulator drives in the ground modem. The adjustment is done at L-band because the effects of the power amplifier and balloon transponder limiting can be compensated for prior to reception by the aircraft.

Not shown in the block diagram of the ground station (but a required part of the experiment's ground station operations) are the balloon telemetry reception and recording facilities, and the normal ground station voice communication facilities for communicating with the aircraft, radar site, and balloon tracking facility.

## 5.2 Balloon

ESRO/ESTEC will supply for the experiment the balloon; balloon equipments; and balloon launching, tracking, and recovery. Figure 5-2-1 is a block diagram of the transponder onboard the balloon. For both the UHF-to-L-band and the L-band-to-UHF frequency conversions, simple frequency translation is employed. The transponder employs class C power amplification, so that the received signal power must be above a minimum threshold level. In addition to the transponder, the balloon will contain a vertically polarized UHF antenna; a right-hand circularly polarized L-band antenna; a telemetry transmitter including temperature, signal reception level, and altitude sensors; a radar beacon; and a power source.

## 5.3 Aircraft

The aircraft will employ both medium-gain and high-gain L-band antenna systems. The medium-gain antenna, manufactured by the Boeing Aircraft Company, is a slotted, cross-dipole configuration having a nominal gain of 5 dB. The high-gain antenna, which is manufactured in France and known as the Dioscures Antenna, is a fixed-array antenna system with a nominal gain of 10 dB. The high-gain antenna is built as two switchable sections located in the front of the aircraft, with one section tilted upward facing the right side and one section tilted upward facing the left side. Using switchable sections permits full balloon coverage, when the aircraft is using the high-gain antenna. A single medium-gain antenna located on top of the aircraft will provide complete aircraft coverage of the balloon for the elevation angles anticipated. During the flight test, only one antenna at a time will be connected to the aircraft transceiver.

The aircraft transceiver used for this experiment is the breadboard transceiver built for the ATS-F PLACE experiment. The breadboard transceiver consists of three units: a receive-transmit (R/T) unit, a modem unit, and a high voltage supply. Figure 5-3-1 is a block diagram of the PLACE experiment transceiver. The R/T unit consists of an L-band diplexer, a receiver-down-converter, and an upconverter-power amplifier. The incoming 1550.48 MHz

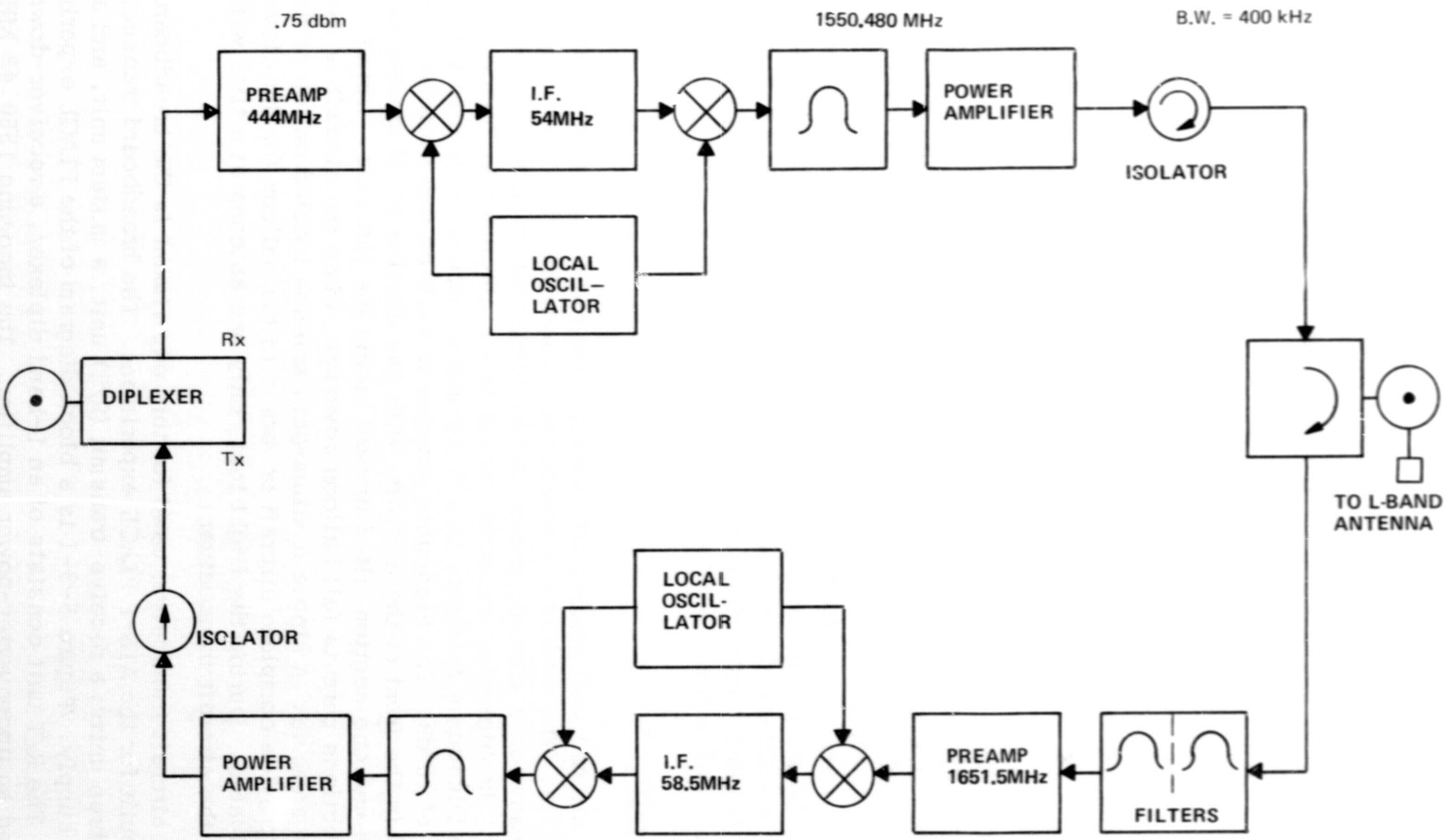
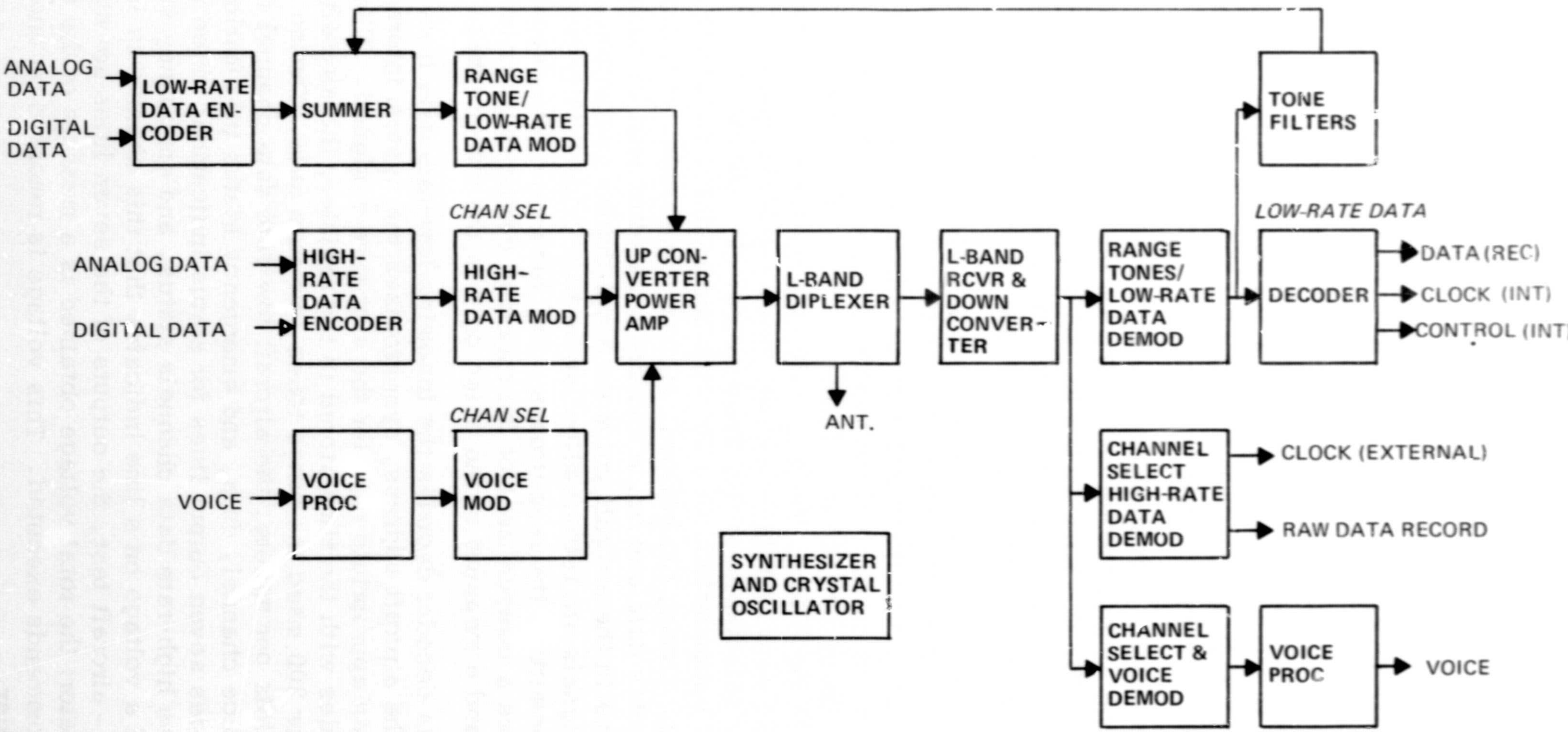



Figure 5-2-1. Balloon Equipment

Figure 5-3-1. Place Experiment Transceiver



signal to the R/T unit from the antenna is channeled to the receiver port by the L-band diplexer (when the R/T unit is used with the Dioscures antenna system, the L-band diplexer is bypassed). The receiver-downconverter amplifies the received signal and converts it to a 70 MHz intermediate frequency, which is then fed to the modem unit. A 60 MHz intermediate frequency (IF) modulated signal from the modem unit is delivered to the upconverter-power amplifier, which converts the 60 MHz IF signal to a 1650.50 MHz 100 W L-band signal. The L-band signal is delivered through the diplexer to the antenna. The high-voltage supply provides all the voltages for operation of the R/T unit. The modem unit contains its own internal power supply.

The modem unit in the aircraft is identical to the unit located in the ground station except for the inclusion of a decoder and activation circuitry. The input 70 MHz IF signal to the modem from the R/T unit is demodulated by three separate demodulators; the range tones low-rate data demodulator, the high-rate data demodulator, and the voice demodulator.

The demodulated low-rate data and tones are separated by filtering. The low-rate data are delivered to a decoder located in the modem units which provides for the internal control and event indicator activation. Outputs are provided from the modem unit of baseband low-rate data, high-rate data, tones, and voice. These outputs are also delivered to the modem unit range tones low-rate data modulator, the high-rate data modulator, and the voice modulator. The high-rate data modulator and the voice modulator each can transmit on any one of three selectable carrier frequencies. The outputs of the modulators are summed and upconverted to a 60 MHz intermediate frequency for delivery to the R/T unit. During the balloon - aircraft experiment, only a ground-to-aircraft simplex data and voice channel evaluation will be conducted, as limited space in the aircraft prevents a full duplex evaluation. The received baseband signals are retransmitted so as to provide a fully loaded spectrum when retransmitting the range tones. The high-rate data demodulator Costas loop provides a measurement of the received carrier-plus-noise in the in-phase arm and a measure of the noise only in the out-of-phase arm.

The decoder decodes the incoming low-rate data from which it identifies the aircraft address, synchronizes the system internal clock, and shifts into an appropriate register the slot time assigned. When the clock time coincides with the time stored in the register, the aircraft automatically transmits for 200 msec the range tones low-rate data. During 10 specified 200 msec slots per minute, the aircraft low-rate data channel transmits and receives voice channel, data, and emergency status information. The decoder provides seven output lines for status indication: three voice channels status, three high-rate data channels status, and emergency status. The presence of a voltage on a line indicates that this channel is in use. For the balloon - aircraft test, the outputs of the seven lines are summed in the event indicator; the total voltage obtained is a measure of the number of indicator commands executed. This voltage is recorded on one channel of the paper recorder.

The 60 MHz IF input from the R/T unit to the modem unit is delivered from the modem unit to a frequency converter, which changes the 60 MHz IF to a 10 MHz IF for external use.

A data test set receives the demodulated high-rate data channel output. The data test set, a Frederick 600N, performs a bit error measurement on the received 2,047-bit-per-frame pseudo-random code.

The time code generator provides a NASA 36-bit serial code readout of time in hours, minutes, seconds, and tenths of seconds, as well as a time reference for coordinating and evaluating the recorded data (as for the ground station).

The telemetry recorder, a Phillips Analog 7, provides for the recording of the voice, low-rate data, carrier-plus-noise analog, noise analog, NASA time code, and the bit error pulses from the data test set. A paper recorder records the received signal AGC and the event indicator output voltage level. A 1-min time marker is provided by the time code generator. If a marker channel is not available on the paper recorder, the epoch indicator level output from the event indicator unit will supply the 1-min time reference.

## 6. TEST PROGRAM

The test program will consist of three phases, as follows:

(1) Hardware checkout and test at the manufacturer's plant

(2) Preflight tests at the ground station site in Aire-sur-l'Adour, France

(3) Two types of actual flight tests (continuous tests, and control system tests for multiple access).

The hardware checkout and tests will insure that all equipments are operating within specifications. The preflight tests will verify that the equipment integration and calibration have been properly implemented. The tests to be conducted during flight operations will be designed to evaluate the ATC concepts proposed for the NASA/ATS-F PLACE experiment. These flight tests will be conducted in two phases, as follows:

Phase 1. Continuous tests involving two-way ranging, ground-to-air simplex data transmission, and ground-to-air simplex voice transmission

Phase 2. Control system tests for multiple access, involving gating of the range tones transmitted from the aircraft, discrete aircraft address, and system status monitoring onboard the aircraft. In addition, digital data and voice quality tests similar to those in Phase 1 will be performed.

During each flight, ranging, voice, and data communications tests will be performed. These parameters will be measured principally as a function of aircraft terrain, elevation angle, received carrier-to-noise, and type of antenna employed. The aircraft terrain will be a function of the flight path selected and will depend on the flight approval obtained by ESRO from the appropriate civil air authorities.

Figure 6-1 illustrates a typical flight path. The aircraft will fly constant elevation circular flight paths relative to the balloon. Elevation angles at $5^{\circ}$, $10^{\circ}$, $15^{\circ}$, and $20^{\circ}$ will be employed. A Phase 1 flight and a Phase 2 flight will require approximately 4 hr each of flight time, so that a total of 8 hr of flight time will be needed. Each of the two flight phases will consist of four 45-min segments at a constant elevation, with 15 min allowed for changing to a new elevation. The minimum flight time required to conduct a complete sequence of the NASA Balloon-Aircraft Ranging, Data and Voice experiments is 8 hr, and each repeat of the sequence will require an additional 8 hr minimum flight time. It would be desirable to have at least two flight sequences for a total time allocation of 16 hr.

## 7. DATA PROGRAM

The major data parameters to be evaluated as a result of this experiment are the ranging error, voice intelligibility, and data transmission error.

### 7.1 Ranging Error

Figure 7-1-1 shows the geometric configuration of the experimental system. From the known ground station location, radar azimuth and elevation position data of the aircraft and the balloon, and balloon altitude, and using the radar station as the reference datum point, the aircraft-to-balloon and the ground-to-balloon ranges can be obtained as follows:

$\phi_A$ = azimuth angle of aircraft

$\theta_A$ = zenith angle of aircraft

$\phi_B$ = azimuth angle of balloon

$\theta_B$ = zenith angle of balloon

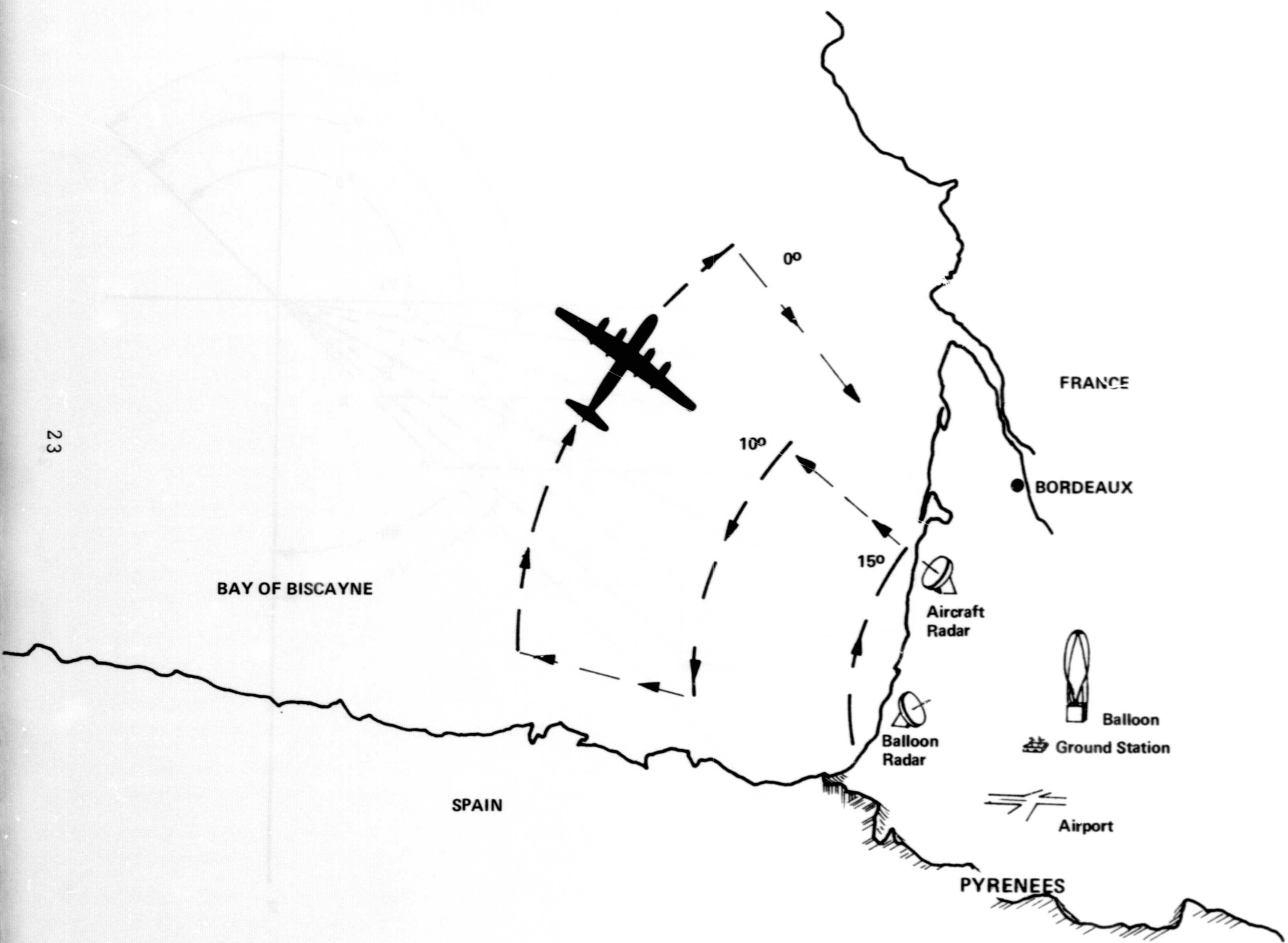
$h_A$ = aircraft altitude

$h_B$ = balloon altitude

$R_G$ = distance from ground station to radar site

$\phi_G$ = azimuth angle of ground station.

Figure 6-1. Typical Flight Path



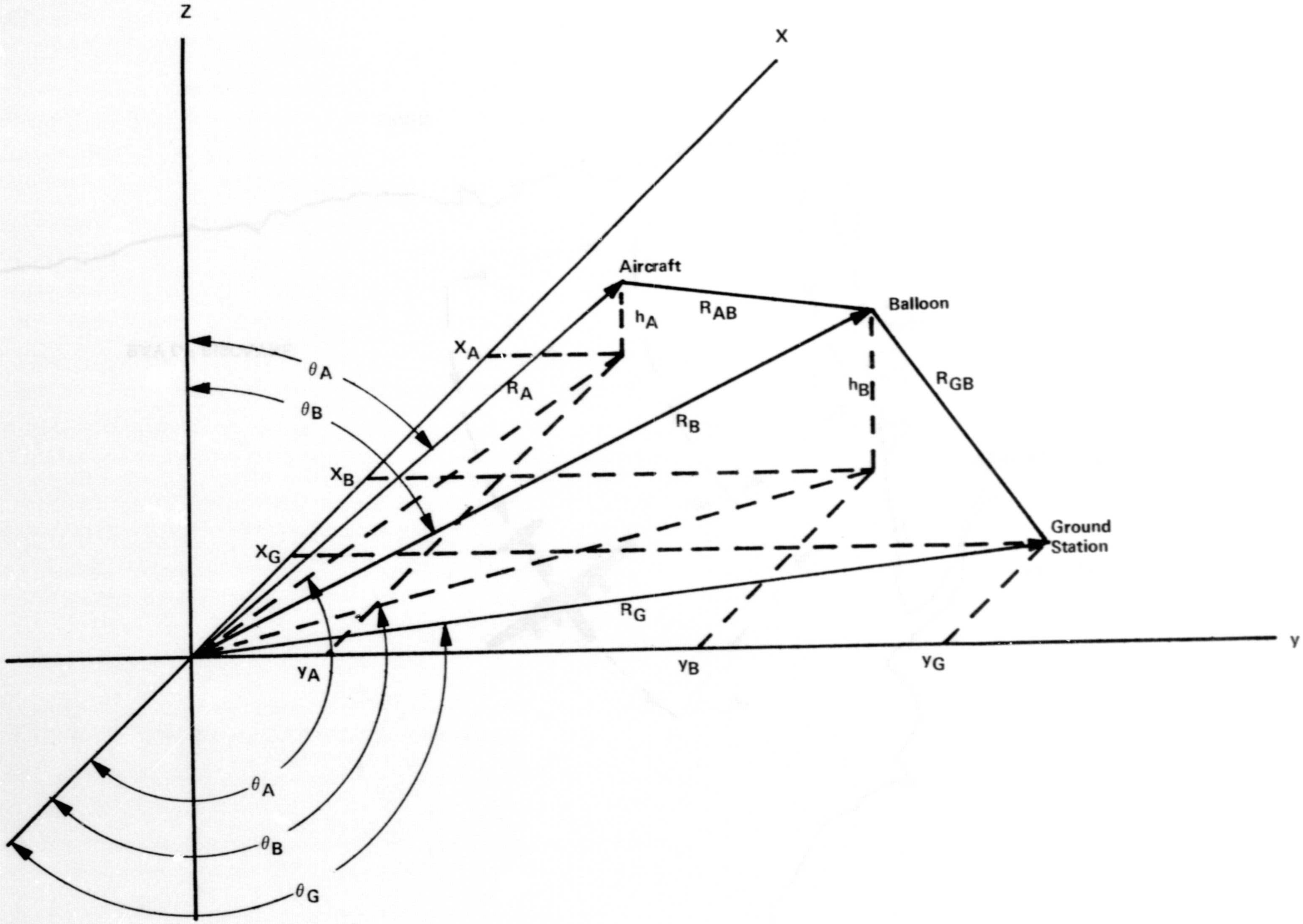



Figure 7-1-1. Balloon-Aircraft Ranging Experiment Geometric Configuration

Position of aircraft:

$$X_A = h_A \tan\theta_A \cos\phi_A$$

$$Y_A = h_A \tan\theta_A \sin\phi_A$$

$$Z_A = h_A .$$

Position of balloon:

$$X_B = h_B \tan\theta_B \cos\phi_B$$

$$Y_B = h_B \tan\theta_B \sin\phi_B$$

$$Z_B = h_B .$$

Position of ground station:

$$X_G = R_G \cos\phi_G$$

$$Y_G = R_G \sin\phi_G$$

$$Z = 0 .$$

Aircraft-to-balloon range:

$$\sqrt{(h_A \tan\theta_A \cos\phi_A - h_B \tan\phi_B \cos\phi_B)^2 + (h_A \tan\theta_A \sin\phi_A - h_B \tan\theta_B \sin\phi_B)^2 + (h_A - h_B)^2} .$$

Balloon-to-ground station range:

$$\sqrt{(R_G \cos\phi_E - h_B \tan\theta_B \cos\phi_B)^2 + (R_G \sin\phi_G - h_B \tan\theta_B \sin\phi_B)^2 + h_B^2} .$$

Figure 7-1-2 is a flow diagram of the path traveled by a tone from ground transmission to ground reception. At the ground station the tone time delay is determined by measuring the angular phase shift between the received tone and the transmitted tone. By eliminating fixed-time delays inherent in the system, the range from the ground station to the balloon to the aircraft can be computed. By subtracting from this quantity the ground-station-to-balloon range as determined from the radar data computations, the aircraft-to-balloon range results. The derivation of the relationships for computing the aircraft-to-balloon range is as follows.

System primary time delays:

$T_1$ = ground station transmitter

$T_2$ = ground station-to-balloon path

$T_3$ = UHF-to-L-band section of balloon transponder

$T_4$ = balloon-to-aircraft path

$T_5$ = aircraft transceiver

$T_6$ = aircraft-to-balloon path

$T_7$ = L-band-to-UHF section of balloon transponder

$T_8$ = balloon-to-ground-station path

$T_9$ = ground station receiver.

During calibration of the system the fixed time delays will be measured as one parameter.

$$T_F = T_1 + T_3 + T_5 + T_7 + T_9 .$$

Also,

$$T_2 = T_8 = T_{GB}$$

$$T_4 = T_6 = T_{AB}$$

$$T_{total} = T_F = 2T_{GB} = 2T_{AB}$$

$$T_{AB} = \frac{T_{total} - T_F - T_{GB}}{2}$$

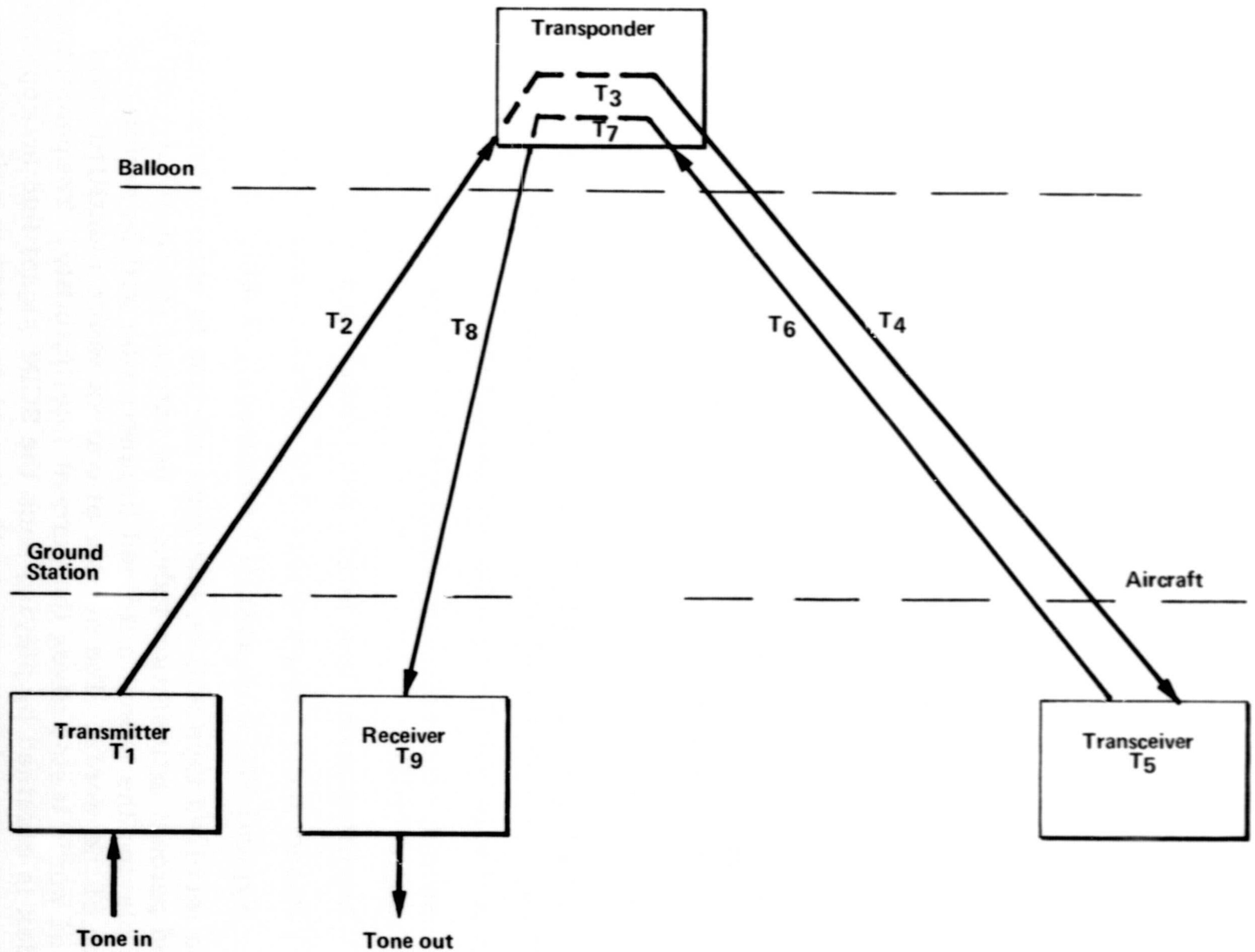



Figure 7-1-2. Tone Path Time Delay Diagram

where

$$T_{GB} = \frac{R_{GB}}{C}$$

$$T_{total} = \frac{\theta}{360f}$$

$$R_{AB} = C \times T_{AB}$$

| | | |
|---|---|---|
| C | = | speed of light |
| f | = | tone frequency |
| $R_{GB}$ | = | ground-to-balloon range from radar |
| $\theta$ | = | tone phase shift in degrees |
| $R_{AB}$ | = | balloon-to-aircraft range. |

The balloon-to-aircraft range measured by tone ranging will be compared with the balloon-to-aircraft range computed from the radar data. An error analysis will be performed with the radar data used as the reference.

## 7.2 VOICE INTELLIGIBILITY

A standard test tape will be transmitted from the ground station and the resultant output audio signal from the aircraft receiver will be recorded.

The test tape will contain the following text:

a. Speech communication index meter for each elevation angle (SCIM)

b. Modified rhyme test (MRT, 200 words): 8 min

c. Phonetically balanced test (100 words): 4 min

d. Typical ATC messages (10 sentences): 2 min.

The received tape will be analyzed off-line to obtain percent intelligibility and percent articulation index. The percent intelligibility will be obtained by playing the tapes to trained listeners who will be required to identify each of the words. The number of correct words identified divided by the number of words tested gives the percent intelligibility. The percent articulation index is obtained by playing back the SCIM signal into an appropriately programmed computer, which analyzes the signal-to-noise in selected frequency bands and assigns a figure of merit (FOM) to each frequency band. The sum total of the figures of merit for each of the frequency bands analyzed gives the percent articulation index.

7.3 DATA TRANSMISSION ERROR

The data transmission error is measured using both the low-rate data channel and the high-rate data channel. The high-rate data channel is tested by transmitting a 1,200-bit pseudo random code and determining the number of bit errors occurring in the received code. The bit errors are recorded on tape so that a distribution of the number of bit errors as a function of time can be obtained. The data channel bit error probability is obtained by dividing the number of bit errors in a specified time by the number of bits transmitted during that time.

The low-rate data channel transmits specific commands to the aircraft. Failure of the aircraft to receive and execute a correct command response represents a command error. The data channel command error probability is obtained by dividing the number of commands in error by the number of commands transmitted.

8. EXPERIMENT SUPPORT

ESRO will be requested to supply the following support:

a. Install and interface NASA equipment in the ground station and in the aircraft

b. Provide one technician in the ground station and one technician in the aircraft for equipment checkout, maintenance, and operation

c. Provide a complete data package to NASA by 1 November 1971. The content and format of the data package shall be determined jointly by NASA and ESRO.

NASA will provide one engineer at Aire-sur-l'Adour from 6 September 1971 to 19 September 1971. The engineer will be responsible for the following items:

a. On-site coordination with ESRO

b. Providing training for ESRO technicians on the operation and maintenance of the equipment

c. Coordinating the test program operation

d. Providing quick-look evaluation of real-time data

e. Verifying that all the required data are being collected and that these data will be included in the ESRO data package to be supplied to NASA.

## 9. EXPERIMENT SCHEDULE

Table 9-1 illustrates the overall aircraft-balloon experiment schedule.

Table 9-1

Experiment Schedule

| Experiment Event | Date |
|---|---|
| Transceiver unit completion | 18 June 1971 |
| Aircraft test and support | 11 June 1971 |
| Equipment delivery | |
| Ground station unit completion | 18 June 1971 |
| Ground station test and support | 11 June 1971 |
| Equipment delivery | |
| Test plan | 17 May 1971 |
| Integration and system testing | 15 July 1971 |
| Completion | |
| Shipment to Europe | 19 July 1971 |
| European aircraft and ground station installation completion | 13 August 1971 |
| Preflight checkout completion | 20 August 1971 |
| Flight test program start | 23 August 1971 |
| Flight test program completion | 1 October 1971 |
| Delivery from ESRO of test data package | 1 November 1971 |
| Preliminary report | 15 January 1972 |
| Final report | 15 March 1972 |